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STRAIN-SLIP FOLIATIONS IN LOW-GRADE METAMORPHIC ROCKS, VICTORIA

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Abstract

Strain-slip foliations due to deformations which preceded, were synchronous with, or post-dated advanced recrystallization were studied in phyllites and schists from Victorian metamorphic belts. Pre-recrystallization foliations are represented by domains of oriented mica; the geometry of the foliations is dependent on the number of deformations which took place before the re-crystallization. In the one example of pararecrystallization strain-slip foliation, the domains consist of closely spaced shear planes. The nature of post recrystallization strain-slip foliation depends on the rock involved: in phyllites they are kink zones and fine planar shears, in the crystalline schists they are narrow domains of mylonite. The geometry of these foliations is invariably discordant to that of pre-recrystallization foliations.

Introduction

Strain-slip cleavages in Ordovician sediments of C. Victoria were described recently (Beavis 1964a). This cleavage was restricted to pelitic rocks: in pure siltstones and slates it consisted of planar shears; in the interlaminated zones of complex oscillatory graded greywackes it was represented by conjugate first-order shears, or, more commonly, by conjugate second-order shears. No distinction could be made between shear cleavage and strain-slip cleavage. The study of strain-slip cleavage has now been extended to low-grade metamorphic rocks exposed in E. and W. Victoria.

Whereas, in C. Victoria, the strain-slip cleavage was imposed during the last phases of the main folding, and was more or less synchronous with the mild recrystallization of the sediments, examples of strain-slip foliations resulting from pre-, para-, and post-recrystallization deformation were recognized in the schists. This paper describes the strain-slip foliations observed; where practicable, microscopic fabric analyses supplement the mesoscopic and microscopic observations. Although the material was collected over a wide area, it is possible that some foliation styles may be present in the schists but were not noted.

Sincere thanks are due to Mr A. A. Baker who collected and made available some of the Orbost material, and to my wife for her painstaking care in the preparation of figures of specimens.

Prerecrystallization Strain-Slip Foliation

The schists of both NE. and SW. Victoria were developed by mimetic recrystallization of the deformed parent sediments (Tattam 1929, Wells 1956). In general, then, the foliations in these schists are an emphasis of deformation structures imposed before recrystallization. As many as four foliations have been noted.

An example from the Casterton schists, at Wando, shows intensely folded lithological layering, S, which represents the original bedding; an axial plane foliation S′; and two conjugate foliations S″, symmetrical about S′ ,formed during a late phase of the folding responsible for S′. Both S′ and S″ are restricted to pelitic layers and are marked by domains of biotite flakes (Fig. 1). S′ clearly represents original

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slaty cleavage, and S'' original conjugate strain-slip cleavage. It was noted that one set of S'' (S''_a) was more prominent than the other (S''_b), S''_b frequently being visible only microscopically.

Wells (op. cit.) recorded boudinage in psammitic beds of the Casterton schists. The conjugate strain-slip cleavage has disrupted fine psammitic laminae to form microboudins (Fig. 2a). Conjugate S'' and microboudins occur only in the altered

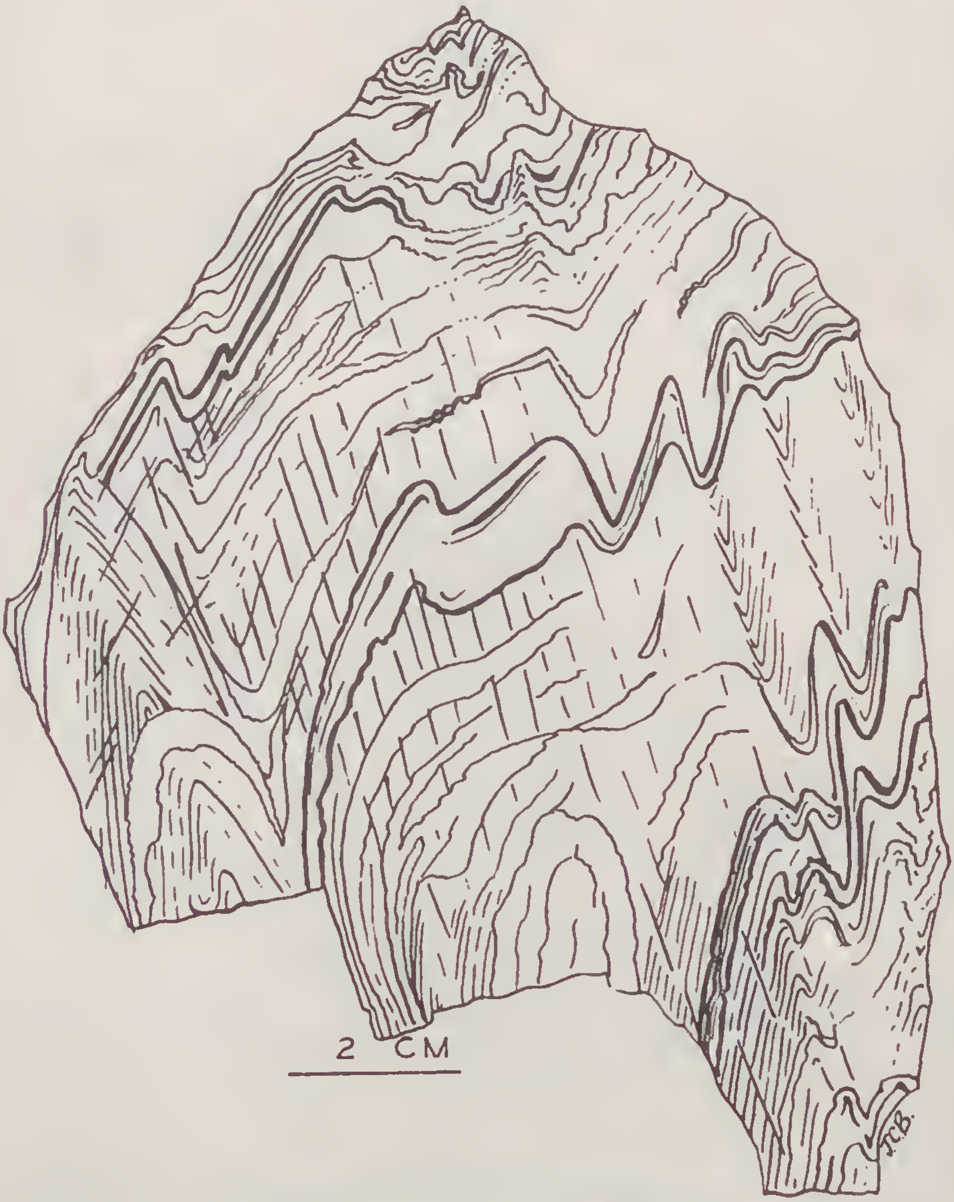

FIG. 1—Foliations in biotite schists, Wando.

schists which were originally interlaminated zones of oscillatory graded beds. In S′ and S″ the biotite flakes normally lie with {001} parallel to the S plane defined by the biotite. In some cases, however, {001} makes an angle with S″; this may be a second-order effect (Fig. 2b). Microscopic analysis of the biotite subfabric (Fig. 2c) emphasizes the dominance of S′; the point maximum for {001} biotite is normal to this foliation. S″ are not clearly defined on the diagram, but the orientation of biotites in these foliations is reflected in the spread about the point maximum.

Although the quartz grains show no obvious dimensional orientation, the in-

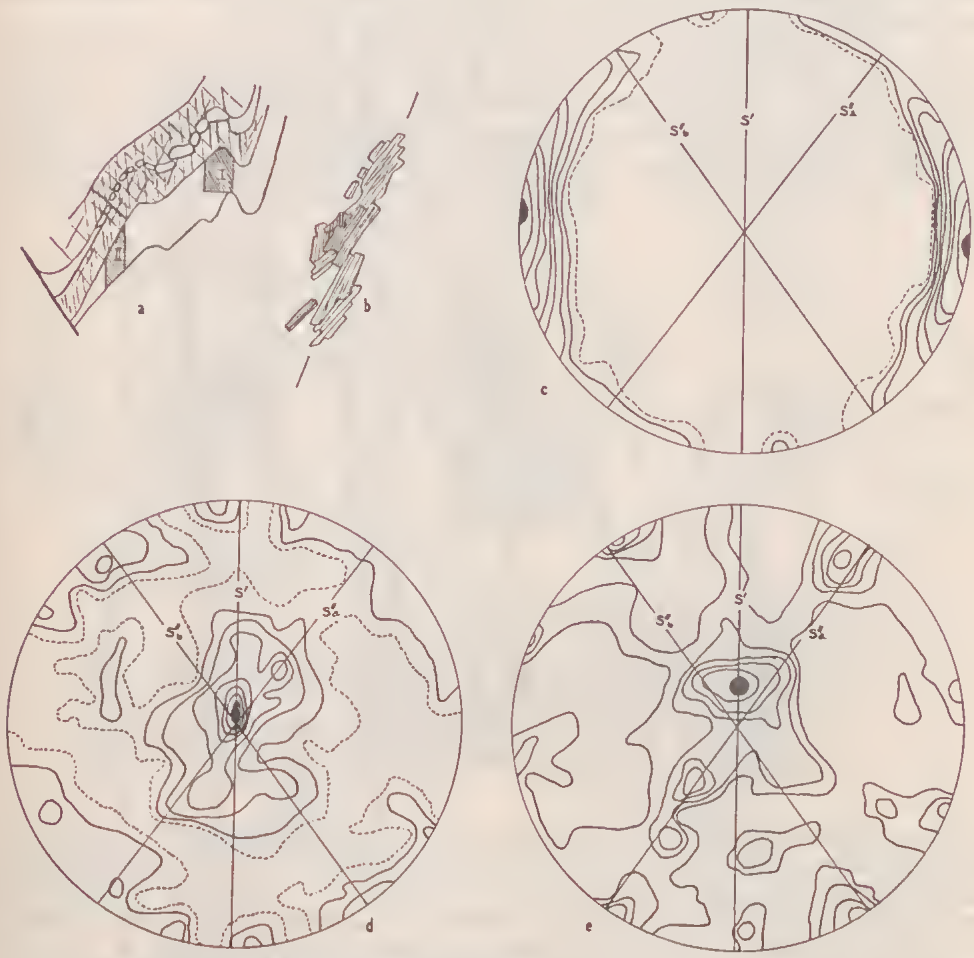

Fig. 2—Microscopic analysis of Casterton Schist.
- a. Microboudins in psammitic lamina.
- b. Biotite flakes lying in S″.
- c. 200 {001} biotite. Contours ½-1-2-4-5-8-10-14-16%.
- d. 200 [0001] quartz on hinge of small fold; subarea 1 of Fig. 2a. Contours ½-1-2-3-4-5-6-7%.
- e. 200 [0001] quartz on limb of small fold; subarea 11 of Fig. 2a. Contours 1-2-3-4-6-8%.

fluence on the [0001] quartz subfabric of S′ and S″ is clearly seen in Fig. 2d and 2e. Tests on both subareas analyzed showed a high degree of homogeneity in the [0001] quartz; in both subareas [0001] lies in the foliations, a result noted in schists from S. of Beechworth (Beavis 1964b). The high concentrations of [0001] lie close to the axis B defined by the intersection of S′ S''_a and S''_b. In Fig. 2e, the greater strength of the girdle S''_a reflects both the prominence of this plane over S''_b and the orienting influence of S. This subfabric has triclinic symmetry.

Both the biotite and quartz fabrics were inherited; there is no evidence of deformation of either quartz or biotite, and the small quartz and mica crystals of the parent sediment formed oriented nuclei during the recrystallization.

Biotite schists at Tawonga, in NE. Victoria, have only two apparent foliations: a a folded lithological layering S and an axial plane foliation S″, which may be a fracture cleavage. The constituent minerals are not deformed. The small folds in S have a chevron style; the axial plane foliation associated with these folds is not truly penetrative, but is restricted to the hinges of the small folds. In these domains {001} biotite is still parallel to S. Here, fracture cleavage was imposed before recrystallization.

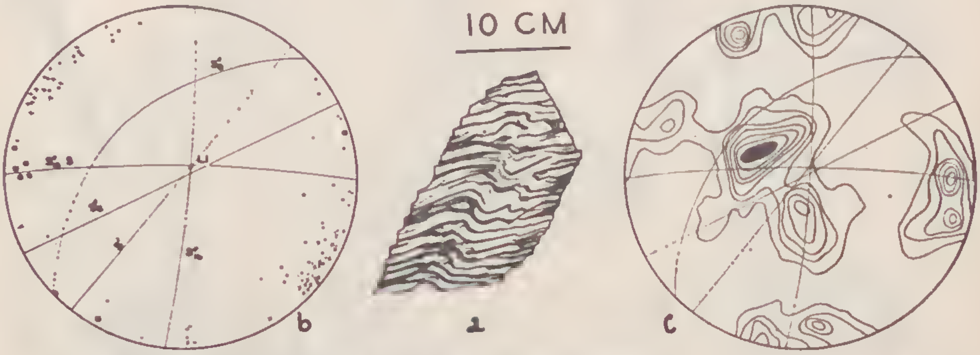

FIG. 3—Quartz biotite schist, Princes Highway, Orbost.
a. Foliations in schist.
b. Crosses indicate poles to {001} of biotite lying in S and dots, poles {001} of biotite lying in S''_a. Circled points are biotites which have suffered post-recrystallization deformation.
c. 200 [0001] quartz. Contours 1-2-3-4-5-6-8%. Foliations and lineations shown on b and c are those visible on the small specimen from which thin sections were cut.

A quartz-biotite schist from Orbost is of particular interest in that it suffered two unrelated deformations before recrystallization; this is evidence of a postrecrystallization deformation also. The mesoscopic geometry is treated only superficially here; more detailed work has yet to be completed. The most prominent foliation is the lithological layering, S, and the least prominent, mesoscopically, is the axial plane foliation S′, of the first folding. This latter foliation, however, is microscopically dominant. A late phase of the first deformation imposed a conjugate strain-slip cleavage, S''_1. S has been folded into small chevron-style folds, the hinges of which form the strong lineation L_1. S''_1 is parallel to S, S''_{1b} cuts S''_{1a} almost at right angles. The second deformation involved the superposition of a strain-slip cleavage S''_2 which deformed the earlier planar and linear structures;

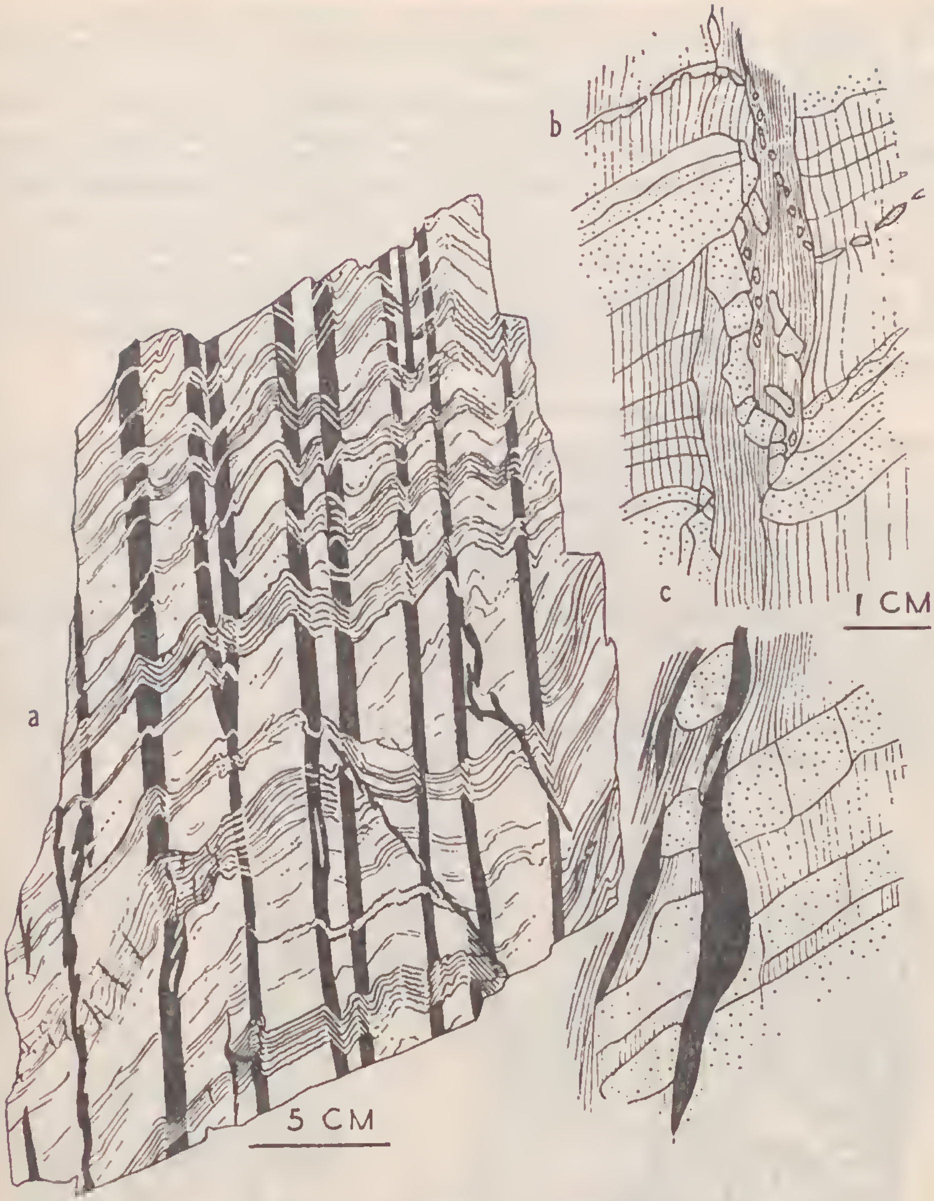

FIG. 4—Strain-slip foliation in developing phyllonite NE. of Woods Point.
a. Cleavage domains and small folds.
b. Detail of cleavage domains.
c. Detail of second-order shears in interlaminated zone.

transposion of S on S''_2 is particularly obvious. A post-recrystallization deformation is suggested by a series of relatively widely spaced parallel discrete shear planes, S''_3. Fig. 4a shows S, S', S''_{1b} and S''_2.

Microscopic analysis of the biotite and quartz subfabric is shown in Fig. 3b and 3c. Fig. 3b shows that {001} biotite is statistically parallel to S', irrespective of the foliation in which the biotite lies; S''_3 has had some influence on the biotite subfabric and those biotite flakes parallel to this surface show deformation characteristics. This is a contrast with other biotite subfabrics examined during the present work; {001} biotite was parallel, or nearly so, to the foliation in which it lies. The quartz has a strong dimensional orientation, the plane containing the maximum and intermediate dimensional axes lying parallel to S'. The [0001] quartz fabric which, like the biotite fabric, has triclinic symmetry, has no apparent relationship to the planar and linear structures observed mesoscopically.

Pararecrystallization Strain-Slip Foliation

Strain-slip foliation developed during recrystallization was noted in one area only—on the margin of a phyllonite-mylonite belt NE. of Woods Point. The rarity of this class of strain-slip foliation is not unexpected; during recrystallization the condition of the rock would tend to militate against shear cleavage development. In the Woods Point phyllite, the strain-slip foliation is marked by domains of shearing up to 1 cm thick. Although the domains, apparently, are sharply bounded, microscopic examination shows that this is not so. Midway between any two domains single shear planes are spaced at intervals of 0·2-0·4 mm. As the domains are approached, the spacing decreases, until, within the domains, individual shear planes are spaced at 0·01 mm or less. The cleavage domains, then, are made up of large numbers (1000±) of shear planes; the displacement on the domains is the sum of the small displacements on each plane.

FIG. 5—Strain-slip cleavage in schists, Beechworth.
a. Cleavage domains and microcoulisse folds.
b. 200 [0001] quartz from microcoulisse fold. Contours 1-2-3-4-5-6%.

Where the domains cross interlaminated thin siltstones and phyllite, second-order shears have been induced (Fig. 4b). Across these zones, the first-order shears are curved, and are refracted at the boundaries. In quartzite laminae, the cleavage planes anastomose; for a cleavage plane to actually cross a quartzite lamina, however, is very rare, and the microfolding of these laminae was usually by flexure. Deformation of the phyllite can be visualized as laminar flow with very closely spaced flow planes. Thus, within the shear domains at least, the developing phyllite

FIG. 6—Conjugate strain-slip cleavage in phyllite, Mt St Bernard.

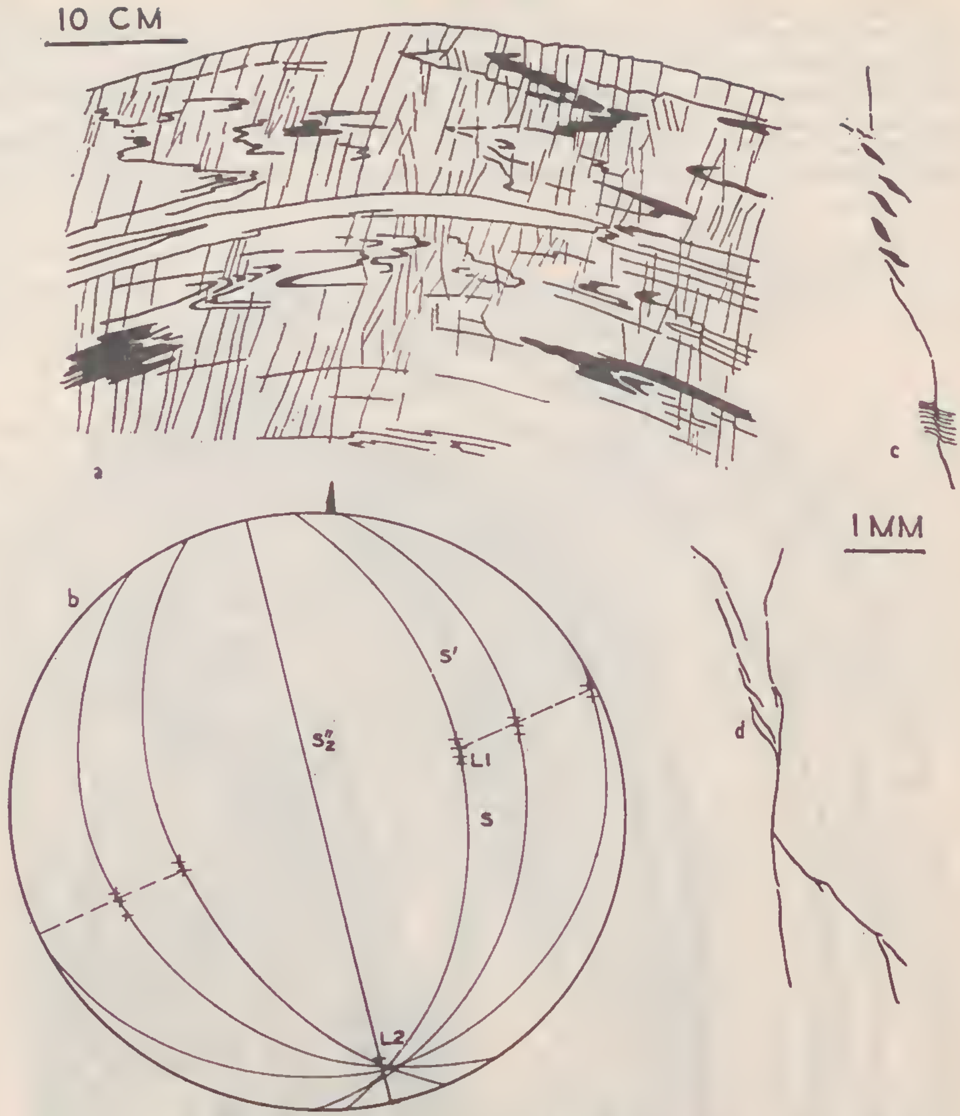

FIG. 7—Strain-slip cleavage in phyllite, Mt Feathertop.

a. Profile of part of a second-generation fold showing smaller folds of the first generation, original bedding, and first-generation axial plane cleavage deformed by S″.
b. Geometry of fold of Fig. 8a.
c. Second-order shears in S″.
d. Kinks and conjugate strain-slip cleavage.

was in a condition approaching viscous; the quartzites, however, remained competent (Fig. 4c). Any clear disruption of quartzite by cleavage planes seems to have been restricted to laminae less than 0·2 mm thick.

Post-recrystallization Strain-Slip Foliation

Superposed folding, during which this foliation was induced in schists and phyllites, appears to have occurred on a regional scale in the Mitta Mitta, Beechworth, and Upper Ovens Valley areas. Locally, in the Tawonga-Mt Hotham and Beechworth areas, very intense strain-slip cleavage and superposed folding is also associated with major faults.

An example of strain-slip cleavage, formed during fault movement, from near Beechworth, is illustrated by Fig. 5a. The rock is a layered quartz-biotite schist, the layers representing original bedding lamination (S). The strain-slip cleavage (S″) has deformed S, with the formation of **microcoulisse** folds, domains of shearing forming the fold limbs. The cleavage domains, 0·5-3·5 mm thick, consist of finely crushed mica and microlenses of quartz, the texture frequently approaching mylonite. Although not prominent, there is a second conjugate set of cleavage cutting across the fold limbs.

Microscopic analysis of the quartz subfacric (Fig. 5b) of the **microcoulisse** folds shows that the symmetry of this sub-fabric is triclinic. [0001] quartz lies in girdles coincident with the conjugate S″ and with S planes of an earlier deformation. The strong point maximum lies in the lineation defined by the intersection of the stronger S″ (S''_a) and S′ of the prerecrystallization deformation.

In the area W. of the West Kiewa Thrust (Beavis 1962) phyllites have had strain-slip cleavage superposed by the stresses responsible for the fault movement. At Mt St Bernard, the cleavage forms two irregular sets (Fig. 6); the only other foliations are the original bedding and, locally, a very weak axial plane cleavage of the first (Benambran) folding. The strain-slip cleavage here consists of fine shear planes; the folding on the cleavage is very fine, and usually has a conjugate style.

Closer to the thrust, the strain-slip cleavage in the phyllites is more intense, and movement along the cleavage has superposed relatively large (10 cm-1 metre) folds on the previously folded rocks. A profile of part of one of these superposed folds is shown in Fig. 7a and the geometry of the fold on Fig 7b. There is considerable variation in both the style of the strain-slip cleavage and in the nature of the cleavage domains. Incipient cleavage is marked by slight kinking of the earlier foliations (Fig. 7d); this passes along the domains into distinct shear fractures. Although the effects of lithological changes are slight, they were sufficient for second-order shears (Fig. 7c) to develop in the layers of less fine material. Two conjugate sets of cleavage may occur locally (Fig. 7d). This style is frequent enough to be significant. In this area, further work is under way since at least three deformations are known to have occurred.

Discussion

Irrespective of the time relationships of recrystallization and deformation, the style of the strain-slip cleavage appears to depend on the nature of the rock involved. Thus, second-order shears are found only in fine textured phyllites and schists; they are not found in the finest textured rocks, nor in the coarser crystalline schists. Conjugate cleavage also shows some restriction but this is not as well defined as that of the second-order shears. In any case, conjugate srain-slip cleavage appears far more frequently than was anticipated. While the actual nature of the cleavage domains, too, depend to a large extent on lithology, this is controlled more by the time relationship between deformation and recrystallization.

The geometrical relationship of the strain-slip cleavage depends on whether this cleavage was imposed by deformations responsible for other foliations, or whether it was the result of unrelated deformations. In most Victorian schists, the pre-recrystallization strain-slip cleavage is either an axial plane foliation at the large folds, or is symmetrically related to the axial planes. These foliations were obviously imprinted at a late phase of the deformation responsible for the main folding. Recrystallization has given a mimetic emphasis to the cleavages, which appear in the schists as strong foliations. Both biotite and quartz subfabrics of these schists have an intimate relationship with the mesoscopic fabric. The Orbost material is an exception, and further work will be required here.

Pararecrystallization strain-slip cleavage is rare, and it is impossible to generalize from one set of examples. In these examples, movement of incompetent rock apparently occurred by laminar flow within the cleavage domains.

As would be expected, there is a geometric discordance between pre-recrystallization and post-recrystallization foliations; any accordance would be fortuitous. In the post-recrystallization strain-slip cleavage, the nature of the domains is controlled by lithology. The coarser crystalline schists have domains with a mylonite texture, and it seems probable that movement occurred by flow in the domains. In phyllites and finely crystalline schists, the cleavages tend to be more or less discrete shear planes.

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